Measuring Salinity

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Abstract

Root-zone salinity reduces crop yields. The extent of the reduction depends on the kinds and concentrations of salts existing in the soil solutions across the field. The salts which cause root-zone salinity typically dissociate into sodium, calcium, magnesium, and sometimes potassium cations together with chloride, sulphate, bicarbonate, and carbonate anions. These ions, when dissolved in soil water and concentrated in excess of plant needs, can disrupt crop water uptake and plant metabolism. We easily recognize the existence of salinity when we see white salt crusts on soil surfaces. But, root-zone salinity may also exist in field locations which never show white crusting. Surveying and mapping a field using geo-physical instruments operating on the soil surface can reveal this hidden root-zone salinity. Although measurements with these instruments are affected by soil texture, chemistry, water-content, temperature, and other factors, basic indices can still be calculated by linking survey measurements with detailed salinity values derived from soil cores extracted as part of the survey.

Introduction and Concepts

Minerals, organic matter, and microbes form the solid matrices of soil through which air and water reside and flow. If a soil consists of 55% solid matrix and 45% pores by volume and the pores are completely filled with water (little or no air), the soil is said to be "saturated." If the soil water is allowed to drain from the saturated pores under gravity, the soil reaches a condition referred to as being at "field capacity" wherein gravitational drainage is minimal and the volume of the pore water has reduced to, say 30%, and the air increased to 15%. If the drained water from the point of saturation were collected and measured for electrical conductivity (designated $EC_{extract}$ or EC_e), the strength of the electrical current passed through the extract reflects the concentration of its dissolved salts. This is the measure of salinity received from analytical laboratories which analyze soil samples from farmer's and rancher's fields. However, crops use less of this gravitational water and more of the remaining pore water until plants can no longer extract soil water. On average, the solutions residing in soil pores, when measured for electrical conductivity ($EC_{solution}$), conduct approximately twice the electrical current and contain about twice the dissolved solutes than indicated by the EC_e-measurements.

Laboratory Measurement

In Canada, the standard measure of soil salinity equals the ease with which a calibrated current of electricity passes through an aqueous solution derived from a representative sample of soil analyzed within a certified soils laboratory. Electrical conductivity, in units of deci-Siemens per metre (dS m^{-1}), measuring aqueous extracts from soil samples saturated with deionized water and drained over-night under a slight vacuum produce repeatable soil salinity values (labelled EC_e). The strength of the electrical current reflects the magnitude of the salt-concentration dissolved in the solution. These salinity values can be further correlated with the electrical conductivity of the solution ($EC_{solution}$) actually surrounding the roots, root hairs and symbiotic flora and fauna. This measures the actual salinity affecting crop growth.

Why Measure

Many growers visit their fields in the fall, taking soil samples to evaluate the field nutrient status. Usually, the top soil at two depths (the A and B horizons) is carefully sampled in representative field locations. These samples are sent to a soil testing laboratory, such as the ALS Laboratory Group to measure soil fertility.

Deficits in fertility relative to the nutrients needed to produce the planned crop require costly inputs of N, P, and other elements. An additional measure of the salinity registered by the soil samples indicates the care necessary in crop selection and in minimizing the fertilizer to that quantity which will be utilized by the crop growing subjected to the salinity.

Measurements of salinity should be viewed within the experience and expectations of the land owner and/or producer. A rule-of-thumb exists relating these electrical conductivity (EC_e) measures of salinity to observable indications in the field. It happens that, for southeast and south-central Alberta, southern Saskatchewan, and likely south western Manitoba, one can follow an approximation applicable to the saline areas in cultivated fields growing annual crops. This approximation can best be done watching the field year-after-year. The long-term, visual occurrence of white surface salts tends to reflect the field's EC_e rating: rarely seen (0-2 dS m^{-1}); infrequently seen (2-5 dS m^{-1}); frequently seen (5-8 dS m^{-1}); almost always seen (greater than 8 dS m^{-1}).

In addition to experience, an expectation of the growing season's soil water reserves plays a role. If soil water reserves in the spring appear to be above normal, such as likely in 2011 (based on the wet 2010 season and the 2010-11 snowcover), one might take a risk in growing a crop with less salinity tolerance. Ample soil water increases the likelihood of diluting soil solutions and decreases the salinity effect on crop yield. On the other hand, if the field soil samples and land owner's experience indicate wide-spread salinity, especially at the hidden or invisible levels, a more extensive salinity investigation and mapping will provide a greater array of information.

Using Salinity Measurements

It happens that crops vary in their tolerance of root zone salinity. A salinity tolerance index (STI) has been developed for Canadian crops (Table 1). The index allows growers to compare crops in order to minimize yield reductions and limit fertilizer applications to where salinity will not compromise its benefits. The electrical conductivities of pore water ($EC_{solution}$) and saturated soil paste extracts (EC_e) were used to calculate the indices, relating crop yield to salinity. The yields of Canadian crops sown in the spring with seed placed directly into saline seedbeds and grown continuously subjected to known root-zone salinity under dryland conditions resulted in comparative response curves (Figure 1). These curves led to the STI values of Table 1. If the crops are irrigated, even just initially through the establishment period, better tolerances can be expected.

Table 1. A Sample of Salinity Tolerance Indices for Canadian Crops (Ranked in Decreasing Order of Tolerance); Abridged from Steppuhn et. al.(2004).

Crop	Salinity Tolerance Index
Tall wheatgrass	11.7
Green wheatgrass	12.5
Beardless wild ryegrass**	11.6
Red beet **	10.4
Pea **	9.0
Broccoli **	9.0
Tall fescue**	8.6
Intermediate wheatgrass**	8.5
Barley	8.3
Tomato **	8.3
Canola (*B. napus*)	8.0
Slender wheatgrass	7.8
Wheat, soft white **	7.3
Alfalfa	6.8
Wheat, durum**	6.7
Potato**	6.6
Flax **	6.6
Corn **	6.6
Lettuce **	5.8
Radish **	5.7
Onion **	5.0
Dry bean **	4.3
Wheat, prairie spring	3.8
Wheat, hard red spring	3.3

** Salts added following emergence of the crop.

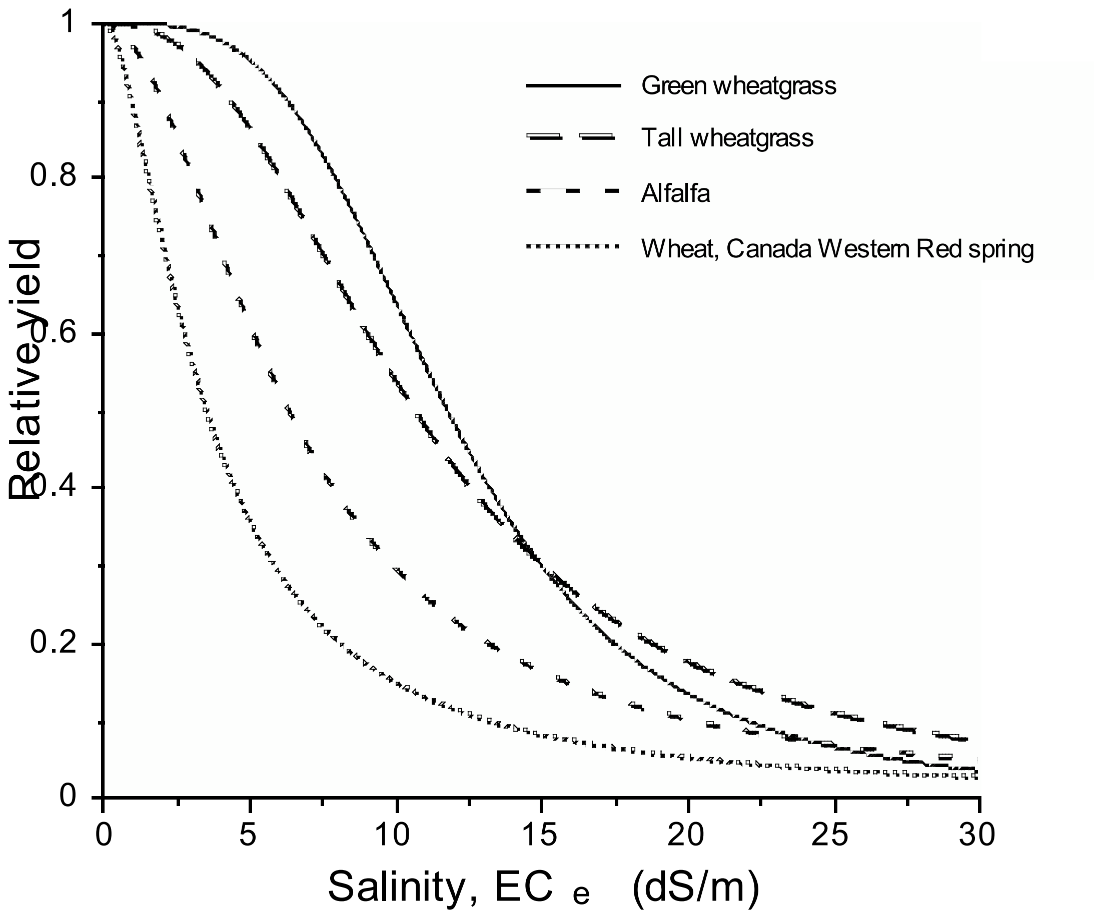

Figure 1. Comparative yield response curves of four selected crops to salinity.

Measuring Salinity in the Field

Field salinity can be measured in situ with either direct contacting electrical resistivity type equipment or non contacting electromagnetic induction type equipment. These methods both provide measurements of the soils' apparent electrical conductivity (EC_a). The EC_a is affected by many soil properties such as texture, moisture content, and temperature in addition to salinity. However, in fields that exhibit spatially variable levels of salinity, salt concentration will typically have the greatest influence on the EC_a and strong correlations can be made between EC_a and EC_e.

A salt-affected profile can be depicted either by changing orientation of the instrument (EM38) or its sensing units (Dual EM) or by changing the electrode spacing (Wenner Array, Veris). Other devices have the ability to read multiple depths by collecting data at different frequencies (Geophex). All systems allow for the rapid collection of large amounts of data which can be used to determine the salinity status of the project area:

Wenner Array The Wenner Array measures the electrical resistivity of the soil (conductivity is the inverse of resistance). This device, also referred to as the four point probe, was one of the first portable devices developed for field data collection. Generally, the probes were fixed along an axis and then inserted into the soil, a current was induced, a reading taken, and then this was subsequently related to a salinity value. The depths of investigation were determined by the spacing used and allowed for the depiction of upper and lower soil profile salinity values.

EM38/31 These instruments are examples of non-contacting type equipment that work on the principle of electromagnetic induction. The EM38 has been a preferred instrument for field use due to its lightweight, ease of operation and the ability to obtain both a horizontal (0.75 m) and vertical (1.5 m) dipole reading with one unit. The EM31 operates on the same principle but readings are obtained to a greater depth; 3 m in the horizontal mode and 6 m in vertical mode.

Veris Technologies Similar to the Wenner Array, the Veris measures the electrical resistivity of the soil. The Veris is a mobile unit that consists of a series of coulters mounted on a trailer that can be pulled by a truck or quad. Typically, the Veris is set to measure to two depths; 30 cm and 90 cm. However, some models can vary the spacing which allows for collection of data from different depths. Stony or dry conditions can create contact limitations that may affect data collection.

Geophex This device is an electromagnetic sensor that can collect multiple frequencies at depths down to 30 m. The handheld ski that contains all sensing apparatus is lightweight and less than 2 m in length.

Applications

The use of easily mobile EC_a measuring equipment and GPS technology enables Agrologists and other professionals to perform field scale surveys in relatively short periods of time. Measuring the EC_a of the soil and developing field scale maps have many environmental and agricultural applications. The Environmental Unit within the Ministry of Agriculture's Irrigation Branch use the EM38 to determine the salinity status of land as part of the Irrigation Certification process. More recently agricultural consultants have been using this technology for precision agriculture applications.

Field Investigation

The Irrigation Branch's Environmental Unit use a dual EM38 and differential GPS (DGPS) system to take simultaneous horizontal and vertical EC_a readings. The DGPS system tags each set of readings with a geo-referenced location that is accurate to within 2 cm. These data are then further processed with a GIS program to create detailed salinity and topography maps of the field.

In the field the operator will typically run the perimeter of the field and then follow transects which are generally spaced between 50 to 70 m (or much closer in anomalous areas). Depending on the application, line spacing will vary; i.e. for a precision agricultural application, line spacing may be the width of the seeding implement.

During the survey, the operator will identify various points in the field from which soil samples should be taken. These samples are taken in order to assist with interpretation of the EC_a readings. For salinity surveys, the soil samples are taken from four to five points in the field covering a range of readings. Soil samples are sent to a soil testing lab and the EC_e along with major ions are determined. Once the EC_e is known it can be correlated with EC_a. If there is a strong correlation ($R^2 \geq 0.75$), the regression equation will be used to convert EC_a readings to EC_e. Finally, with the use of a GIS program, detailed salinity maps can be generated for the field in question.

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